

Influence of selected variables of athletes' special physical fitness on sports performance in pole vaulting

ADAM GEBSKI¹, KRZYSZTOF PERKOWSKI²

¹LIX High School Sports Championship Warsaw, POLAND

²Józef Piłsudski University of Physical Education Warsaw, POLAND

Published online: July 31, 2023

(Accepted for publication July 15, 2023)

DOI:10.7752/jpes.2023.07220

Abstract

The objective of the conducted research was to use modern movement measurement technologies in identifying the influence of selected special physical fitness variables on pole vaulting performance. The study of the top 10 pole vaulters in youth age categories in Poland was carried out prior to the summer Polish Championships (direct start conditioning). The cutting-edge motion measurement technologies Optojump and the Witty system were used by analyzing the following kinematic parameters of the run-up: speed, length and duration of the last two run-up steps, the duration and distance of the take-off spot from the box, and the grip height. Measurements were also made of tests assessing the special physical fitness of the pole vaulters under study: a 30-meter fly run, a standing-position and run-up long jump, a forward throw of a 4-kg medicine ball, and the power and jumping levels of vertical jump (Optojump). The data obtained were compared to the pole vaulting score and pole hardness index. The study found a significant relationship between ground contact time on take-off, grip height and pole hardness index and athletic performance in pole vaulting. The applied physical fitness tests examining the level of motor aptitude in the study group pointed to the influence of power and jumping ability on the ability to use a harder and longer pole and, consequently, to cross the bar at a higher height.

Keywords: kinematics, pole vault, pole hardness index, Optojump, motor skills

Introduction

The study of motor and technical issues related to pole vaulting performance has been extensively researched for many years. Pole vaulting is one of the most complex athletic competitions. It requires athletes to have advanced technical skills contingent on their fitness level (Zagorac et al., 2008; Frere et al. 2010; Gębski and Perkowski, 2015). When studying young pole vaulters, Sullivan et al. (1994) found that grip height had the most extensive correlation with performance. In contrast, age, body weight and speed level showed the most significant correlation with grip height. In their analysis of the results of the 1993 Stuttgart World Championships finalists, Gross et al. (1994) stressed that for the world's top pole vaulters, there is no direct, statistically significant correlation between the value of developed speed on the run-up and the achieved height of the jump. The significance of developing high speeds on the run-up in correlation with the pole vaulting result proves itself in statistical analyses of large groups of subjects, but is not reflected in the direct sporting struggle during top-level competitions. They underlined the significant importance of the take-off in pole vaulting, in particular the reduction of its duration, which results in the transfer of more energy gained in the run-up and take-off to the pole.

The identification of variables that significantly affect the athletic performance in this competition is possible through two methods: experimental or model-based. The first is limited by the ability to access the data sought without interfering with the structure of the jump (Frere et al., 2010). Taking advantage of the latest technological advances and equipping pole vaulting runways with measuring equipment, it is possible to accomplish a number of biomechanical analyses during training and competitions. The current technological level sets a new experimental direction of scientific research involving the use of selected data, closely related to the characteristics of the competition, and allows for advanced assessment of the athletes' motorics in the improvement of start preparation.

In light of the latest scientific studies in the field of pole vaulting (Hanley et al, 2019; Edouard et al, 2019; Gravestock et al, 2018), it should be emphasized that the research work carried out in the conditions of actual sports competition is of particular value. The current practice of sports is a mobile laboratory, which follows athletes during preparation and competitions and uses state-of-the-art technological products. The prerequisite for achieving application values of the obtained data is the search for factors that significantly typify the specifics of the discipline or competition and do not cause unnecessary information noise.

Access to state-of-the-art technologies is required to improve the sports training process. Optojump is one such technology using kinematic analysis of movement that can be applied to the real environment of sports competition. Research on the movement structure of sprinters and jumpers, carried out under competitive

conditions and analysis of their motor preparation, shows the validity and legitimacy of using Optojump technology in this respect (Glatthorn et al, 2011; Blazevic, 2014; Malone, 2014; Rapotan et al., 2023). When used, Optojump technology allows for precise measurements of a variety of parameters that define the run-up of athletes in competition conditions, which is in line with current trends in sports scientific research (Makaruk et al., 2016; Gębski and Perkowski, 2017).

The main objectives of the study were to determine the kinematic and technical variables of special fitness and motor tests affecting the sports result in pole vaulting, which can be measured during competition and training with the Optojump system. It should be hypothesized that some of these speed and jumping indicators, as well as the parameters of the pole used, significantly condition the jump height achieved by athletes.

Material and Methods

Ten pole vaulters undergoing training by the Polish Association of Athletics participated in the study (average age 17.3 ± 1.57 ; average personal best in pole vault before the study 3.98 ± 0.50 m). Approval from the Training Department of the Polish Association of Athletics was secured for the conduct of the study, along with the consent of the subjects (in the case of minors – legal guardians) by submitting appropriate declarations and valid sports and medical examinations.

At the beginning of the summer starting period, the athletes were subjected to the following tests of the level of special physical fitness and analysis of kinematic variables describing the final part of the run-up in pole vaulting. The following were performed:

1. A 30-meter running speed test – “flying” (from the run-up) [s], using Witty technology.
2. Tests to determine strength capabilities in the forward throw of a 4 kg medicine ball [m] and jumping ability and leg power in vertical jump from a 2-step run-up and jump before take-off – Drop Jump (DJ), using Optojump technology and measuring:
 - a) maximum height reached (Hmax DJ [m]);
 - b) maximum leg power achieved (Pmax DJ [W/kg]).
3. Jumping ability tests in measuring the length of the long jump from the spot [m] (Optojump technology) and the length of the long jump from the 14-step run-up [m].

Each of the speed, strength and jumping ability tests was repeated three times by the athletes. The best sample was chosen for analysis.

In terms of assessing technical preparation, measurements were made of:

1. Speed on the run-up
 - a) at a distance of 13 – 8 m before the box (lowering the pole) [m/s].
 - b) on the last 2 steps of the run-up (putting the pole on) [m/s].
2. Length of the last two steps of the run-up [m].
3. Duration of the last two steps [s].
4. Distance of the take-off point from the box [m].
5. Take-off time [s].
6. Grip height [m].

The data from said measurements, collected under realistic pole vaulting conditions, were compared to the obtained jump score and the pole hardness index (the sum of the length [cm] and the manufacturer’s LBS scale hardness value of the pole).

Optojump Next from Microgate, Bolzano, Italy, is a system of one-meter long crossbars placed on both sides of the run-up. Each is equipped with microscopic LED sensors spaced every 1 cm, which record contact time and flight time to the nearest 1/1000th of a second. The set includes a web video camera that records images of the tests being performed and correlates them with mathematical data. The software supplied with the system makes it possible to calculate step length and frequency, speed achieved on take-off, duration and height of take-off, power of take-off, amount of energy expended. The system works in the starting conditions without interfering with the athletes’ ability to perform the jump. The software allows for recording and analyzing the tests performed in real time and correlating this data with the video image. The video camera is compatible with software and computer systems. The Witty timing system is a wireless set of two pairs of photocells and a portable chronometer compatible with Optojump software. This portable system allows for laying a measuring path of the desired length. Preparation of 5 meters of Optojump measuring path (3 meters of measuring strips and 2 meters of supporting cables) at a distance of 3 meters from the box and precise measurement of time (Witty) on the next 5 meters allowed for analysis of the assumed parameters of the last steps on the run-up in the phase of pole establishment and take-off.

The obtained results were compared to the results in pole vaulting and subjected to statistical analysis using STATISTICA 12. PL program from StatSoft®. The variability of the analyzed parameters was presented using the arithmetic mean and standard deviation. The assumption of normal distribution of the obtained data was checked with the Shapiro-Wilk test. The degree of dependence between the measured values was evaluated on the basis of calculated Pearson correlation coefficients. A significance level of $p < 0.05$ was considered statistically significant.

Results

With the Optojump and Witty systems, it is possible to obtain a whole range of kinematic data of the movement task being performed. Based on the available literature on the subject (Petrov 2004; Gębski and Perkowski, 2017), the parameters selected for analysis are shown in Table 1.

Table 1. Results of measurements of selected kinematic variables of the run-up and the parameters of the pole used by the athletes

Variable	N	Mean	Min.	Max.	SD
Speed in run-up 13-8m [m/s]	10	7,95	6,85	8,77	0,54
Speed – 2 last steps [m/s]	10	8,45	7,74	9,59	0,70
Length of penultimate step [m]	10	2,05	1,90	2,23	0,12
Length of last step [m]	10	1,77	1,51	2,15	0,19
Time of flight phase of penultimate step [s]	10	0,13	0,11	0,16	0,01
Time of flight phase of last step [s]	10	0,08	0,06	0,15	0,03
Take-off distance [m]	10	3,50	3,00	4,25	0,36
Contact time on take-off [s]	10	0,13	0,09	0,15	0,02
Grip height [m]	10	4,25	3,70	4,60	0,26
Pole hardness index	10	627,00	600,00	670,00	26,06
Pole vault result [m]	10	4,25	3,70	4,80	0,33

Selected kinematic variables characterize the performance of key phases in pole vaulting technique: lowering and planting the pole and take-off (Petrov 2004). Important elements of the quality of the technique, in addition to speed, are the length of the running steps, in particular the penultimate and last steps (Makaruk et al. 2016) and as well as the distance of the take-off from the box (3.50 ± 0.36 m) and the grip height (4.25 ± 0.26 m) (Frere et al. 2010). It appears that the inclusion of the pole hardness index (627 ± 26.06), a parameter often overlooked in studies due to limitations in access to the characteristics of the poles used by athletes, will also be an important part of the analysis. An analysis of the results obtained by the athletes in motor tests (Table 2) will complete the overview of the level of special physical fitness of the studied athletes. The average results obtained in the following tests: speed (3.31 ± 0.11 s), jumping DJ (0.56 ± 0.04 m), standing-position long jump (2.65 ± 0.10 m) and max power DJ (66.36 ± 8.87 W/kg) indicate the need to train on improving this aspect of special fitness in order to achieve a better final sports result in speed and jumping disciplines (Policastro et al., 2020).

Table 2. Results of physical fitness tests and the achieved result in pole vaulting of tested athletes

Variable	N	Mean	Min.	Max.	SD
30m flying start [s]	10	3,31	3,16	3,53	0,11
Forward throw 4kg mb [m]	10	13,70	11,50	16,20	1,50
Vertical jump DJ [m]	10	0,56	0,47	0,59	0,04
Max leg power DJ [W/kg]	10	66,36	46,70	78,46	8,87
Standing-position jump length [m]	10	2,65	2,51	2,81	0,10
14-step long jump [m]	10	6,03	5,64	6,51	0,29

Table 3 shows the nature of the correlation of the parameters studied. The pole vaulting score is significantly correlated with the grip height (0.827), pole hardness index (0.778) and ground contact time on take-off (-0.689). There was no direct correlation between the indices of speed (the 30-meter run speed test and the speed parameters obtained by the athlete on the run-up), jumping ability, power or the performance characteristics of the run-up, and the sports result achieved. However, the effect of power tested with the medicine ball throw test (0.668) and jumping ability in the long jump from the run-up (0.733) on the ability to use a harder and longer pole at a higher grip (0.824) was reported, which consequently allowed the athlete to achieve a better result in the pole vault. In technical terms, it is certainly necessary to stress the importance of the shortest possible contact time with the ground on the take-off (the so-called “active take-off”).

Table 3. Values of the correlation coefficient of the analyzed kinematic indicators and fitness tests with the result in pole vaulting and the coefficient of pole hardness in the studied group

Variable	Pole vault result	Pole hardness index
30m flying start	-0.390	-0.481
Forward throw – 4kg medicine ball	0.199	0.668*
Max leg power DJ	-0.063	-0.122
Vertical jump DJ	0.105	0.417
Standing-position jump length	0.220	0.587
14 steps long jump	0.423	0.733*
Speed in run – up 13-8 m	0.025	0.289

Speed – 2 last steps	0.429	0.566
Length of penultimate step	-0.123	0.113
Length of last step	-0.004	0.120
Time of flight phase of penultimate step	0.288	0.295
Time of flight phase of last step	0.216	0.142
Take-off distance	0.628	0.548
Contact time on take-off	-0.689*	-0.583
Grip height	0.827*	0.824*
Pole hardness index	0.778*	1.000
Pole vault result	1.000	0.778*

Discussion

In pole vaulting, the pursuit of steady, biologically-driven performance progress must be supported by data that objectively assesses technical and motor preparation.

The kinematic data obtained with the Optojump system show only a small part of the potential of this technology. The high test-retest reliability of the Optojump system ($R = 0.97$) suggests that it is sufficient to produce satisfactory results (Casartelli et al., 2010; Słomka, 2017). Needless to say, basic statistical analyses show that only a part of it is relevant to the improvement of pole vaulting technique and the importance of individual tests in the screening and selection process for this competition (Gębski and Perkowski 2015; Makaruk et al. 2016; Gębski and Perkowski 2017).

From the standpoint of jump biomechanics, the objective of pole vaulters is to transfer energy from the run-up and take-off and accumulate it as extensively as possible in the deflected pole and then use the “propulsion” of the straightening pole to achieve maximum ascent and cross the bar (Frere et al, 2010; Zagorac et al, 2008; Shade et al, 2004). Therefore, research interest ought to be directed at the determinants of this process. On behalf of World Athletics, during the World Athletics Championship finals: the summer championships in London, held on August 08, 2017, and the Birmingham indoor championships, held on March 04, 2018, Hanley et al. (2019); Gravestock et al. (2018) analyzed the speed on the run-up achieved between 11 and 6 meters from the box, the length and duration of the last two steps of the run-up and the speed achieved on them, the take-off distance from the box, the height of the grip, the angle of insertion of the pole, and measurements of the angles between selected somatic parameters, for example, the angle between the thigh and shank of the swing leg in the take-off position. The data obtained were compared across the competing athletes. London recorded an average speed on the take-off between 11 and 6 m from the box of 9.36 m/s (Birmingham – 9.12 m/s) and an average speed on the last step – 8.87 m/s (Birmingham – 9.42 m/s), the average distance of the take-off position from the box: London – 4.09 m (Birmingham – 4.16 m). The values obtained allowed London and Birmingham to achieve an average pole vaulting score of 5.75 m and 5.70 m, respectively. By comparing these results with the results of the present study and the group’s average velocity values of 7.95 m/s (between 13 and 8 m) and 8.45 m/s on the take-off, as well as the distance of the place of the take-off (3.50 m), it is evident that these variables need to be improved in the studied athletes in order to further their progress in pole vaulting. In particular, referring to the best athletes in the world, improvement should be sought in the achieved average pole vaulting performance – 4.25 m. The data achieved in the present study make it possible to identify the variables that are statistically significant in influencing the result in the youth categories in pole vaulting: the time of contact with the ground on the take-off, the grip height, and the pole hardness index. It is very important to strive to achieve the greatest possible speed on the run-up (with proper running technique and pole placement).

Particular importance is given to the ability to increase said speed during the establishment of the pole in relation to the phase of its lowering (the athletes studied reported an increase in this variable of 0.5 m/s), which was also found in the finalists of the two championship events.

Conclusions

Accurate and reliable consideration of the quality of the technique of complex sports competitions requires reaching for the latest scientific advances both in terms of methods of obtaining data and procedures for relating them to acquired values (motor skills or sports performance achieved). Such measures were taken by using Optojump technology in the analysis of pole vaulting technique. The results obtained significantly correlated with pole vaulting performance confirm previous reports in this regard.

The selection of tests underscores the importance of speed and jumping aptitude as potential predictors conditioning the outcome in pole vaulting. In previous papers on this issue, researchers are still searching for optimal tests reflecting the relevant motor aptitudes affecting pole vaulting performance. This paper is a further proposal for the selection of tests for pole vaulters, deriving primarily from recent expert reports. However, the results obtained show small differences in the studied group of athletes. This attests to the similar motor potential of the analyzed group.

Based on the above considerations and the study results, we can formulate the following conclusions:

1. It has been demonstrated that it is possible to determine the kinematic factors determining the outcome in pole vaulting with the Optojump and Witty systems.
2. The hypothesis that the following speed and jumping parameters have a direct effect on the height of the jump in the studied group has been verified: the duration of the take-off and the pole grip height and its hardness index. The effect of jumping ability and power on the ability to use a harder pole at a higher grip has been found. No statistically significant correlation with pole vaulting performance has been observed for the achieved run-up speed and speed level in the study group.
3. In pole vaulting, which is a competition with the highest level of motor coordination and dependent on a great many external variables, the results of standard motor tests (speed, jumping ability, strength, power) should be considered as indicators of individual progress, and not as selection criteria and determinants of the achieved sports result.

Declaration of interest statement

The authors report there are no competing interests to declare.

References

- Blazevic I., Novak D., Petric V. (2014). Relations between kinematic parameters of sprinter's running and specific motor abilities. *Research in Kinesiology*, 4 (1): 22-28.
- Casartelli N., Müller R., Maffiuletti N.N.A. (2010). Validity and reliability of the myotest accelerometric system for the assessment of vertical jump height. *Journal of Strength and Conditioning Research*, 24(11): 3186–3193.
- Drawer S. (2009). Technology for supporting the coaching of the sprints. *New Studies in Athletics* 24: 123-125.
- Edouard P., Sanchez H., Bourrilhon C., Homo S., Frère J and Cassirame J. (2019). Biomechanical pole vault patterns were associated with a higher proportion of injuries. *Frontiers in Sports and Active Living*. <https://doi.org/10.3389/fspor.2019.00020>.
- Frère J.; L'Hermette M.; Slawinski J., Tourny-Cholleta C. (2010). Mechanics of pole vaulting: a review. *Sports Biomechanics* (9): 123-138.
- Gębski A., Perkowski K. (2014). Evaluation effectiveness of attempts motor capacity and parameters of the build applied by Polish Athletic Association for competitors of youth b national team – with reference to pole-vaulters. *Aletica 2014 Banska Bystrica* s. 310-319
- Gębski A., Perkowski K. (2015). The use of modern technologies in the search for factors influencing sports results in pole vaulting. *Physical Education and Sport*, 59 (1): 49.
- Gębski A., Perkowski K. (2017). Identification of chosen variables of the run-up technique affecting results in pole vault. *XXI International Scientific Congress „Olympic Sport and Sport for All”* s. 73.
- Glatthorn, JF, Gouge, S, Nussbaumer, S, Stauffacher, S, Impellizzeri, FM, i Maffiuletti, NA. (2011). Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *The Journal of Strength and Conditioning Research* 25(2): 556-560.
- Gravestock H., Bissas A., Merlino S. (2018). Biomechanical for the IAAF World Championship London 2017 Pole Vault Men's. Leeds Beckett University and IAAF. <https://www.worldathletics.org/about-iaaf/documents/research-centre>.
- Gross H.J; Adamczewski H., Wolf J. (1994). Biomechanical aspects of the pole vault: Analysis of the 4 th IAAF Word Championship. *Budapest 12th International Symposium on Biomechanics in Sports*: 354-356
- Hanley B. Gravestock H., Bissas A., Merlino S. (2019). Biomechanical for the IAAF World Indoor Championships 2018 Pole Vault Men. Leeds Beckett University and IAAF. <https://www.worldathletics.org/about-iaaf/documents/research-centre>.
- Hommel H. et.al. (2009). Biomechanical analyses of selected events at 12th IAAF World Championship in Athletics, Berlin 15-23 August 2009. A Project by German Athletics Federation. Darmstadt: *Deutscher Leichtathletik-Verband*.
- Killing W. (2006). Optimal measurements using Optojump: providing insights into the performance level of young athletes. Part 1. *Leichtathletiktraining die Lehre der Leichtathletik*, 17 (7): 12-15.
- Makaruk H, Porter J.M., Starzak M., Szymczak E. (2016). An examination of approach run kinematics in track and field jumping events. *Polish Journal of Sport and Tourism* 23: 82-87.
- Malone, J. J. (2014). *An examination of the training loads within elite professional football. Doctoral thesis*. Liverpool John Moores University.
- Markovic G. (2007). Does plyometric training improve vertical jump height? A meta-analytical review. *British Journal Sports Medicine* 41: 349-355.
- Petrov V. (2004). Pole vault – the state of the art. *New Studies in Athletics*, 19 (3): 23-32.
- Petrov V. (2008). The five phases of the pole vault performance. European Pole Vault Conference EAA Cologne <https://sponet.fi/Record/4015053>.
- Policastro F., Sardo A., Yazbek F., Acardo A. (2020) Kinematic assessment of the vertical jump in young basketball players. *Journal of Physical Education and Sport* 20 (6):3229-3333 DOI:10.7752/jpes.2020.s6438

- Rapotan A., Mihailescu L., Mihai I. (2023). The impact of Optojump training on the power of lower limbs in female triple jumpers. *Journal of Physical Education and Sport* 23 (2):555-563
DOI:10.7752/jpes.2023.02069
- Schiffer J. (2014). Sports technology. *New Studies in Athletics* 3: 101-102.
- Shade F, Arampatzis A., Brüggemann G.P. (2004). A new way of looking at the biomechanics of the pole vault. *New Studies in Athletics*, 19: 33-42.
- Słomka, K.J., Sobota, G., Skowronek, T., Rzepko, M., Czarny W., Juras, G. (2017). Evaluation of reliability and concurrent validity of two optoelectric system used for recording maximum vertical jumping performance versus the gold standard. *Acta of Bioengineering and Biomechanics*. 19(2):141-147.
- Sullivan J.J, Knowlton R.G, Hetzler R.K, Woelke P.L (1994). Anthropometric characteristics and performance related predictors of success in adolescent pole vaulters. *The Journal of Sports medicine and physical fitness* 34: 84-179
- Zagorac N., Retelj E., Katic R. (2008). Successful pole vault influenced by certain kinematical parameters. *Coll. Antropol* 32 (4): 1133-1139.